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Report summarizes development video compression algorithms that maintain consistent visual quality for video signals transmitted over a hostile channel and create efficient low-power encoder/decoder modules that implement the algorithms.

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Techniques for Video Code Optimization, Data Item #0005

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1. Introduction

The main technological issues for video communication are diverse and they include:

- *Compression efficiency and rate adaptivity.* This requirement results from the need to fit the given video over a certain budget of bit rate. For narrowband wireless channels, the channel status changes dynamically and requires a variable protection against noise,which calls for variable bit rate allocation for the source (video). Thus, adapting the rate is necessary.

- *Robustness against high bit error rate, error recovery and error concealment.* High compression rates as an important issue in video coding. However, resistance to channel errors is equally important. Moreover, the latter calls for a unique class of algorithms. Most video coding techniques utilize interframe correlation to achieve high compression rates, i.e., predict the present frame from the previous one and code or transmit only the difference in frame data. Hence, to reconstruct a frame, the previous frame must be available. Any error on a frame will continue to propagate until a fresh frame is completely coded and transmitted. Furthermore, most techniques use variable length coding in which the length of the code changes based on the frequency of the code word. Variable length codes are very sensitive to errors because data after the error cannot be interpreted correctly. Hence, errors propagate and significantly degrade the image quality. Bit error rates (BER) over radio links could be as high as 10^{-2}-10^{-3}. Error correcting codes adjusted to the worst error rate cannot be used because the actual transmission rate available will be very small and will result in poor image quality. Bearing this in mind, video compression techniques must be devised so that they are immune against such errors. On the other hand, if such errors are not avoidable, they should be hidden in a way to deceive the human eye.

- *Low power and low complexity hardware implementation.* This is a direct consequence of the mobile and portable environment and the new working and living habits worldwide, which require low power and ease of implementation.

To summarize, the algorithmic goal is to develop compression algorithms that maintain consistent visual quality for video signals transmitted over a hostile channel. The hardware goal is to create efficient low-power encoder/decoder modules that implement the compression and decompression algorithms along with recovery capability for lost information.

The video coding problem is still far from being solved in a satisfactory way. None of the existing algorithms or systems yield an acceptable picture with stable quality for mobile environments. These algorithms are very susceptible to noise and other propagation factors. In Section 2, we review the techniques under current investigation to enhance and optimize video transmission over high bit error rate channels. We then present, in Section 3, the efforts currently taking place at the Mobile and Portable Radio Research Group (MPRG) at Virginia Tech to contribute to optimization of transmitted video quality. We conclude in section 4 with observations, recommendations, and plans for future work.

2. Enhancing Video Quality Transmitted over Hostile Wireless Channels

In the following, we review on measures taken to enhance video quality transmitted over high bit error rate channels.

- **Selective Error Correction / Unequal Error Protection / Layered Coding**

These methods separate the data into two parts: sensitive data that strongly impacts the reconstruction quality and other data that just enhance the reconstruction quality. Both of these are coded separately, the former with a robust error correcting code and the latter with a lower complexity procedure.

- **Combined Channel and Source Coding**

In most current video coding systems, channel coders operate independently from source coders. The video encoder is connected to a digital channel with specific error characteristics. The channel coder is treated as part of the digital channel and is designed in a way that the error is, hopefully, below a certain bound. Certain advantages are possible when dealing with the system as a combined unit. The main idea is to integrate the channel and source coders. For time varying channels, this scheme will allow for the optimal rate allocation between source and channel codes, depending on the state of the channel. If the channel is clear, the joint coder will allocate more bits to the source. If the channel is degraded, the joint coder will allocate more bits for error protection. This scheme will lead to a graceful degradation in quality that is more acceptable and will reduce streaks and frame dropping taking place in current systems.

- **Early Synchronization**

Much of the corrupted data can be recovered by including early re-synchronization recovery. In most systems, when an error occurs, the remainder of the block(s) is (are) ignored until the receiver senses the next valid header. If we have the time and processing power to examine the received data, it is possible to find an earlier re-synchronization point and rescue blocks instead of using error concealment methods (see below). The main problem with current synchronization algorithms is that they are exhaustive in nature and, hence, computationally complex.

- **Error Concealment**

Errors are corrected as much as the coding allows. The remaining errors should be concealed before display. The concept is simply, if you cannot avoid it, hide it. The basic idea is to replace corrupted block data with data from a nearby uncorrupted block. If the number of damaged blocks is not high, the human eye will not perceive the replacement. Error concealment schemes depend heavily on the characteristic of the video sequence and viewer perception. In a sequence with a little motion, this technique will go undetected by the viewer. However, for sequences with fast motion, such a concealment technique will result in perceivable artifacts in the video.

- **Efficient Video Processing Architectures**

All of the previous measures require extensive computation power to process a new frame every one-thirtieth of a second. On the other hand, reception of video is no longer a passive process. New emerging applications call for real-time interactive manipulation of video. This requirement necessitates an optimized architecture to carry out these processing tasks.

3. Current Research Efforts at MPRG

MPRG developed a powerful simulation tool that supports the accurate study of video transmission over wireless channels. The motivation was multifold because existing tools lacked the depth necessary to simulate the desired complex communications system. Existing tools also lacked the realistic channel models and employed over-simplified assumptions. In addition, using ready tools such as Matlab is very slow because of the huge amount of data involved in the processing. The developed tool, Reconfigurable Simulation of Video Performance (RSVP), achieves the desired level of complexity and includes the appropriate models and error handling codes (visit http://www.mprg.ee.vt.edu/research/rsvp/rsvp.html).

RSVP supports the investigation of video quality assessment. This is an important issue because no objective measurements for picture quality exist. The traditional signal quality measurements, such as the signal to noise ratio, do not have a strong correlation with subjective video quality ratings. We demonstrated a decoupling between bit error rate (BER) and peak signal-to-noise ratio (PSNR), signaling a loss of confidence on BER as a

basic metric of digital system performance. Then we introduced a statistical approach to predicting video quality based solely on physical layer parameters. The mean error event length, $\lambda_{distance}$, is a metric derived from the physical layer that facilitates the prediction of expected video quality across systems with different channel coding algorithms. This metric proved to be uniformly consistent in predicting video quality for sequences corrupted by Additive White Gaussian Noise (AWGN) and protected by convolutional, Reed-Solomon (RS), and concatenated (convolutional and RS) codes.

RSVP also supports the investigation of the following issues:

- Relationship between channel and video coding.
- Interaction of physical-layer coding with upper layers.
- Groundwork for algorithm development to code video with respect to channel condition.
- Propagation and interference in LMDS.
- Co-channel and adjacent channel interference.
- Effects of vegetative fading and rain fading.

Another important effort currently taking place is the investigation of the use of the current wormhole runtime reconfigurable architecture. This architecture, also developed at Virginia Tech, implements a flexible programmable video coprocessor. The processor targets operations in the Discrete Cosine Transform (DCT) domain. Most video coding algorithms utilize the DCT. DCT domain processing offers several advantages. First, we need to process less data. Second, we save the time and resources needed to decompress before processing and compress after processing. This rewards us with an average computational savings of 30 percent. Third, some of the DCT domain algorithms require less computational power. Filtering is an excellent example where multiplications are more computationally efficient than convolutions. Fourth, there is no need to adjust the system configuration; all playback and other modules will be left untouched. We have identified six basic processing tasks that contribute to a wide variety of operations frequently needed by multimedia applications. These tasks are resolution conversion, frame rate changing, quality and rate control (bits per pixel), filtering, video compositing, and video cut detection. We have also completed a survey of those algorithms capable of performing these operations in the DCT domain.

4. Conclusion

In this report, we have reviewed techniques that MPRG is currently investigating to enhance and optimize video transmission over high bit error rate channels. We have also briefly presented the current contributions of MPRG at Virginia Tech. Now that we have developed the right tools, we have ambitious plans to pursue several topics:

- The topics discussed in section 3.
- The study of joint video/wireless coding.
- New metrics for quality of service prediction and mobile video receivers/transmitter design.
- The study of the effects of fading envelopes on video quality.
- The investigation of early re-synchronization methods to recover bulk of uncorrupt data.
- The modeling of accuracy for different mixtures of compression techniques.